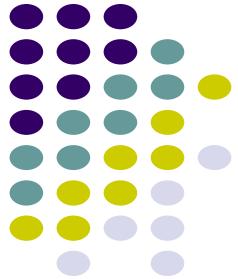
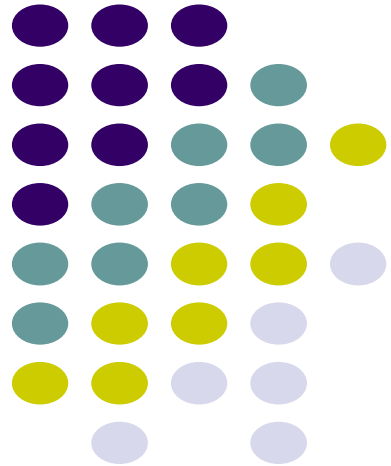


Computer Networks

Lect. 8

Network Layer

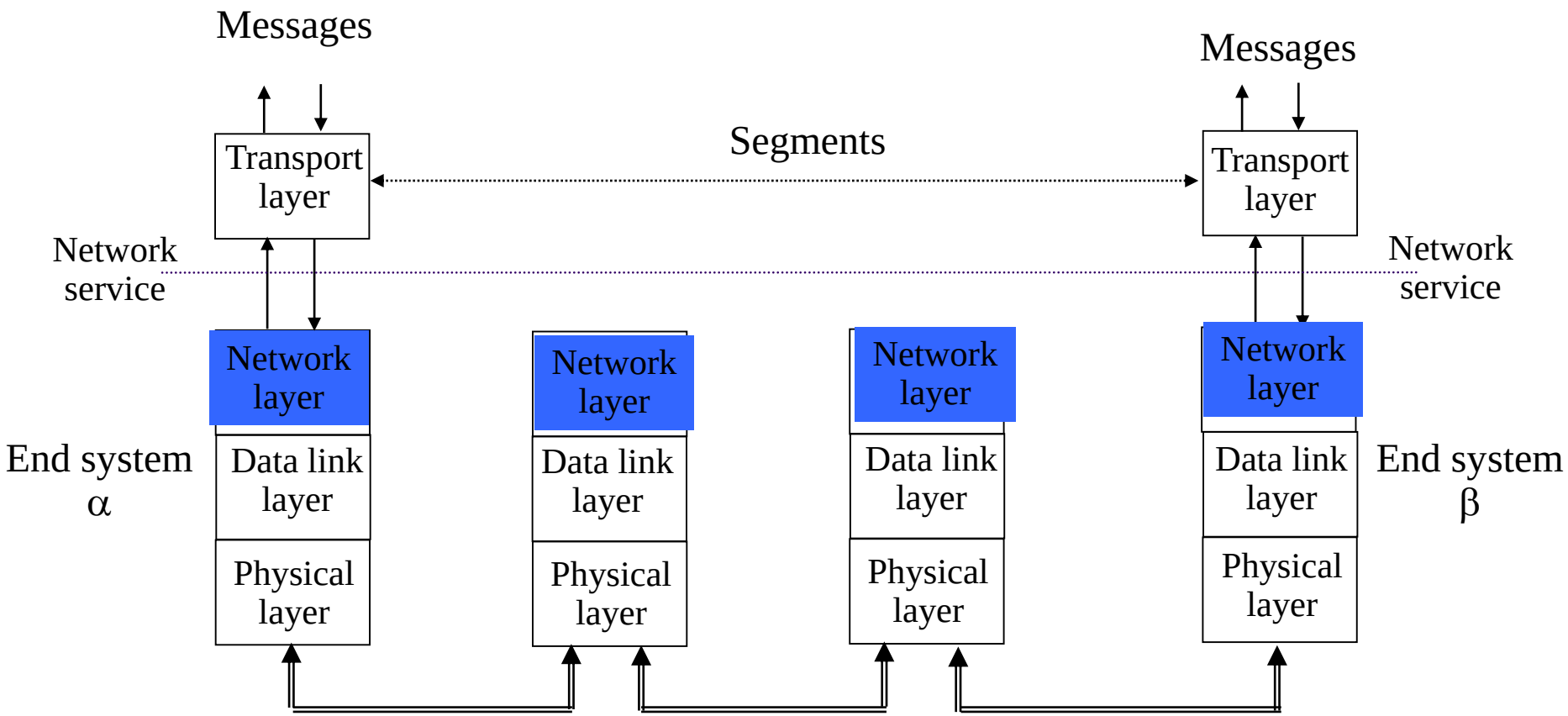
Routing



Network Layer

- Concerned with getting packets from source to destination.
- The network layer must know the topology of the subnet and choose appropriate paths through it.
- When source and destination are in *different networks*, the network layer **(IP)** must deal with these differences.

* **Key issue:** *what service does the network layer provide to the transport layer* (connection-oriented or connectionless).


Messages
Messages
Segments
Transport layer
Transport layer
Network service
Network service
Network layer
Network layer
Network layer
Network layer
Data link layer
Data link layer
Data link layer
Data link layer
Physical layer
Physical layer
Physical layer
Physical layer
End system α
End system β

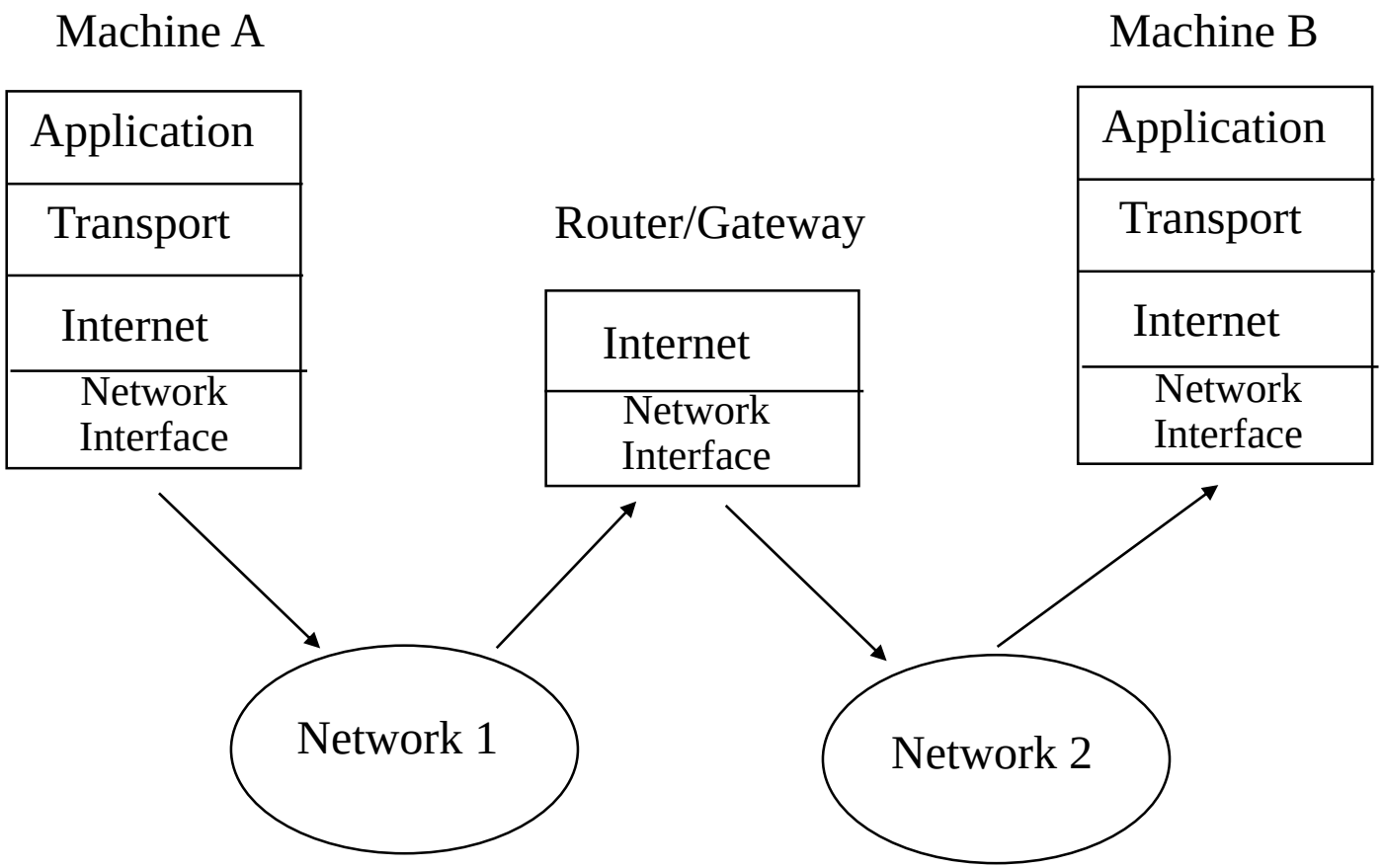

Machine A
Application
Transport
Internet
Network Interface
Router/Gateway
Internet
Network Interface
Machine B
Application
Transport
Internet
Network Interface
Network 1
Network 2

Figure 8.3

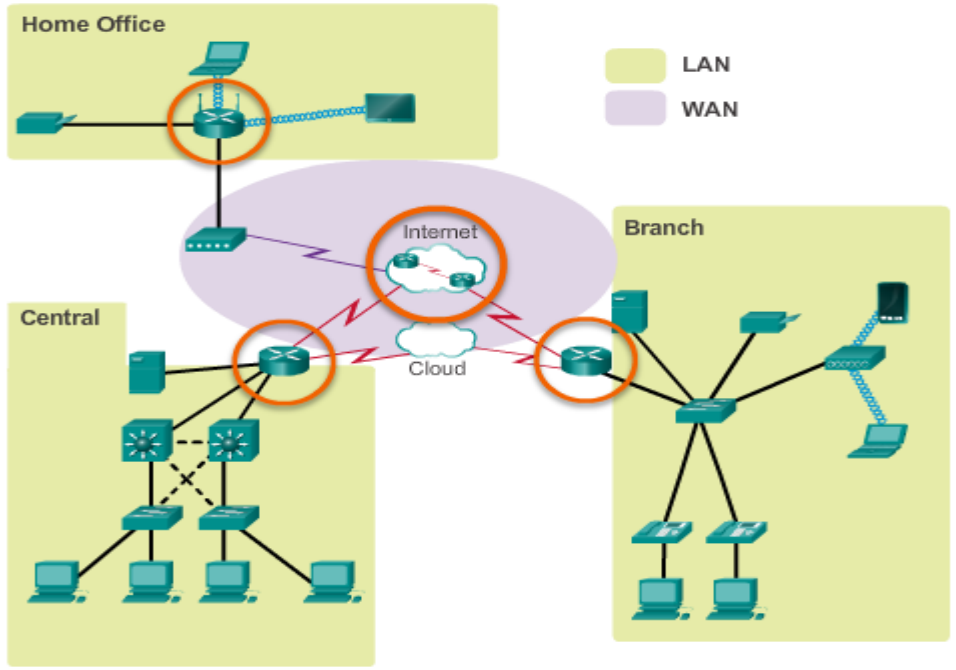
Routing

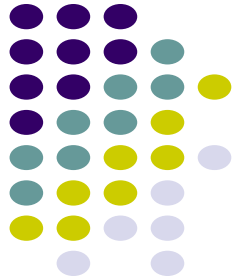
Routing algorithm:: that part of the Network Layer responsible for deciding on which output line to transmit an incoming packet.

- Remember: For virtual circuit subnets the routing decision is made ONLY at set up.

Routers Interconnect Networks

- Routers can connect multiple networks.
- Routers have multiple interfaces, each on a different IP network.





- **Routing** is the process that a router uses to forward packets toward the destination network.
- A router makes decisions based upon the destination IP address of a packet.
- In order to make the correct decisions, routers must learn the direction to remote networks.

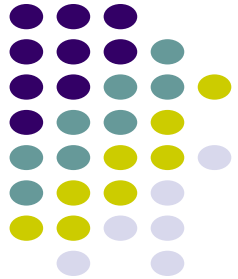
Outline

- **Introduction to Static Routing**
- **Dynamic Routing Overview**
- **Routing Protocols Overview**

Routers Choose Best Paths

- Determine the best path to send packets.
  - Uses its routing table to determine path
- Forward packets toward their destination
  - Forwards packet to interface indicated in routing table.
  - Encapsulates the packet and forwards out toward destination.
- Routers use static routes and dynamic routing protocols to learn about remote networks and build their routing tables.

- When routers use dynamic routing, this information is learned from other routers.
- When static routing is used, a network administrator configures information about remote networks manually.



Static

Uses a programmed route that a network administrator enters into the router

Dynamic

Uses a route that a routing protocol adjusts automatically for topology or traffic changes

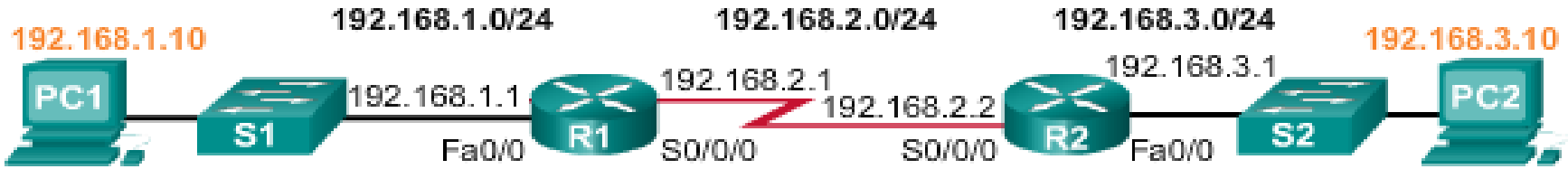
Document Network Addressing

Network documentation is a form of technical documentation. It is the practice of maintaining records about networks. The documentation is used to give administrators information about how the network should look, perform and where to troubleshoot problems as they occur.

- As the purpose of network documentation is to keep networks running as smoothly as possible while minimizing downtime when repairs are necessary, essential parts of network documentation include.
- Map of the entire network to include locations of hardware and the cabling that connects the hardware

Network Documentation should include at least the following in a topology diagram and addressing table:

- Device names
- Interfaces
- IP addresses and
- subnet mask
- Default gateways

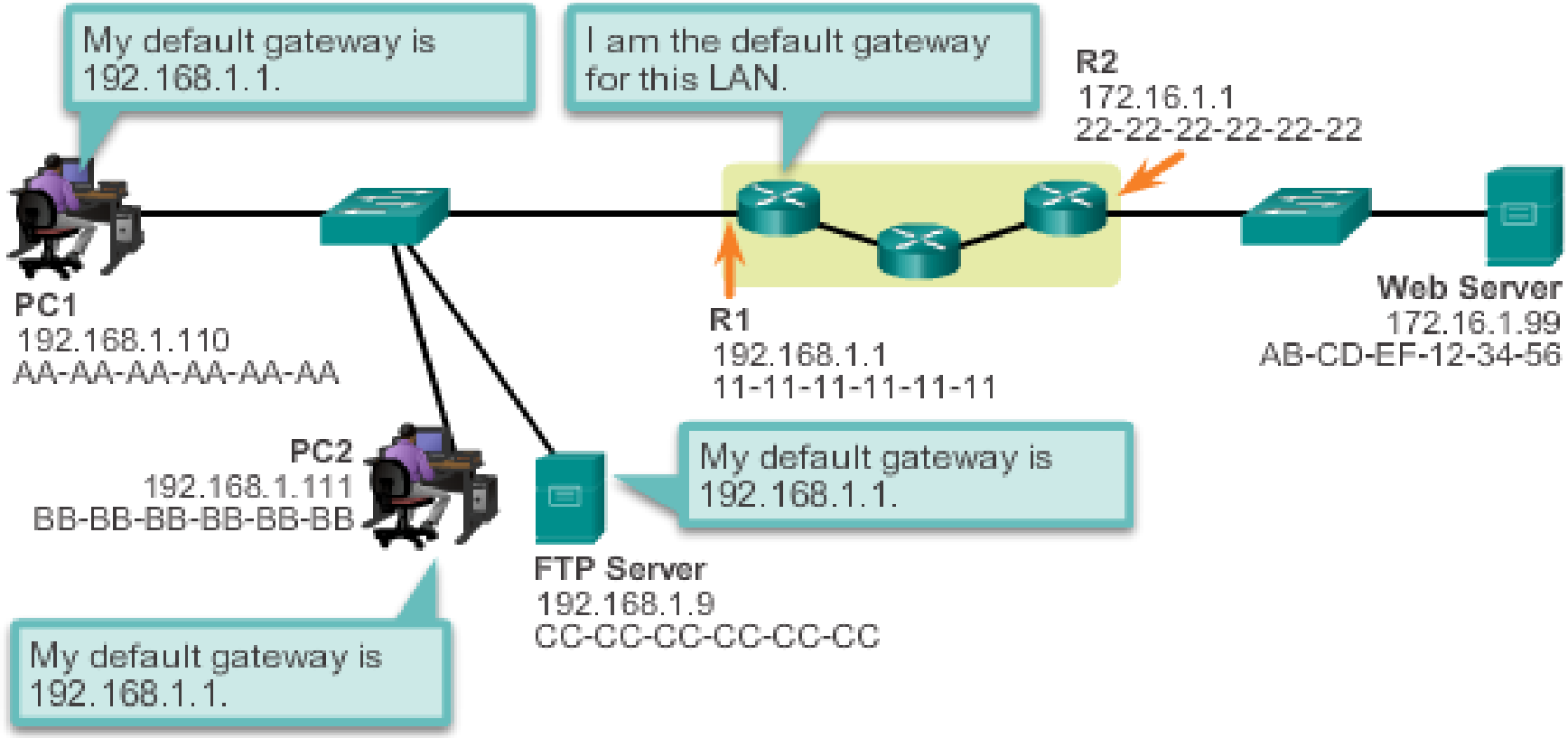


Device	Interface	IP Address	Subnet Mask	Default Gateway
R1	Fa0/0	192.168.1.1	255.255.255.0	N/A
	S0/0/0	192.168.2.1	255.255.255.0	N/A
R2	Fa0/0	192.168.3.1	255.255.255.0	N/A
	S0/0/0	192.168.2.2	255.255.255.0	N/A
PC1	N/A	192.168.1.10	255.255.255.0	192.168.1.1
PC2	N/A	192.168.3.10	255.255.255.0	192.168.3.1

Default Gateways

- **IP address** - Identifies a unique host on a local network.
- **Subnet mask** - Identifies the host's network subnet.
- **Default gateway** - Identifies the router a packet is sent to to when the destination is not on the same local network subnet.

Destination MAC Address	Source MAC Address	Source IP Address	Destination MAC Address	Data
11-11-11-11-11-11	AA-AA-AA-AA-AA-AA	192.168.1.110	172.16.1.99	



- **A subnet mask :**is a number that defines a range of IP addresses that can be used in a network.
- Subnet masks are used to designate subnetworks, or subnets, which are typically local networks LANs that are connected to the Internet.
- Systems within the same subnet can communicate directly with each other, while systems on different subnets must communicate through a router.
- A subnet mask hides, or "masks," the network part of a system's IP address and leaves only the host part as the machine identifier

- A common subnet mask for a Class C IP address is 255.255.255.0. Each section of the subnet mask can contain a number from 0 to 256, just like an IP address. Therefore, in the example above, the first three sections are full, meaning the IP addresses of computers within the subnet mask must be identical in the first three sections. The last section of each computer's IP address can be anything from 0 to 255.
- For example, the IP addresses 10.0.1.201 and 10.0.1.202 would be in the same subnet, while 10.0.2.201 would not. Therefore, a subnet mask of 255.255.255.0 allows for close to 256 unique hosts within the network (since not all 256 IP addresses can be used).
- Large networks with several thousand machines may use a subnet mask of 255.255.0.0. This is the default subnet mask used by Class B networks. The largest Class A networks use a default subnet mask of 255.0.0.0.

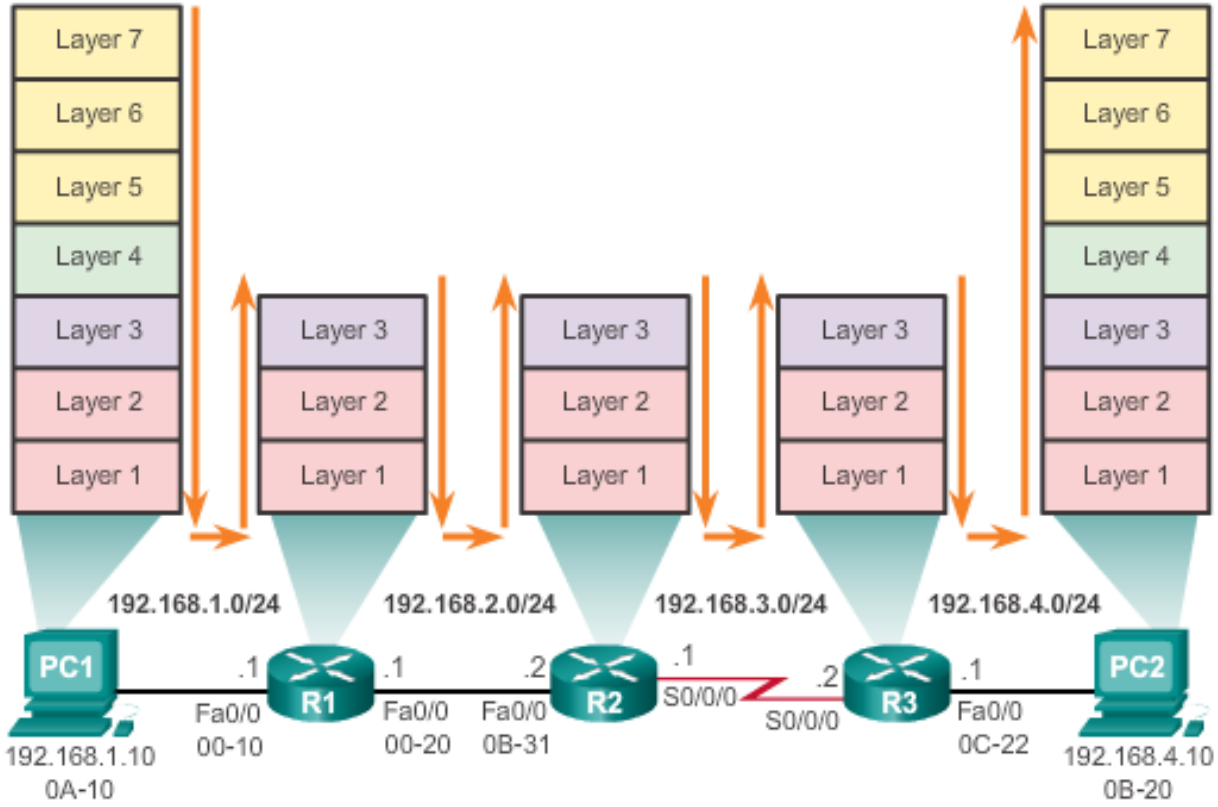
- /8 = 255.0.0.0
- /16 = 255.255.0.0
- /24 = 255.255.255.0
- /32 = 255.255.255.255
- 192.168.1.0/24 = 192.168.1.**0**-192.168.1.**255**

Enable IP on a Host

- **Statically Assigned IP address** – host is manually assigned the IP address, subnet mask and default gateway.
- **Dynamically Assigned IP Address** – IP Address information is dynamically assigned by a server using Dynamic Host Configuration Protocol (DHCP)

Router Switching Functions

Encapsulating and De-Encapsulating Packets



Static route operation

- Static route operations can be divided into these three parts:
  - Network administrator configures the route
  - Router installs the route in the routing table
  - Packets are routed using the static route
  - A static route is manually configured.

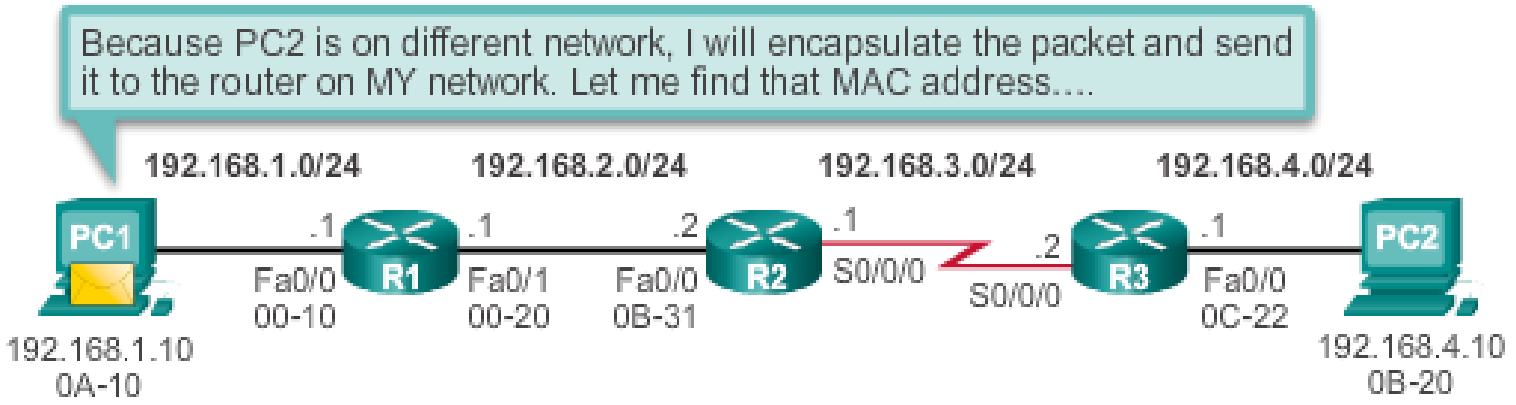
Contents of routing tables

- *network id*: The destination subnet.
- *metric*: The routing metric of the path through which the packet is to be sent. The route will go in the direction of the gateway with the lowest metric.
- *next hop*: The next hop, or gateway, is the address of the next station to which the packet is to be sent on the way to its final destination
- *interface*: such as eth0 for the first Ethernet card, eth1 for the second Ethernet card, etc.

- The primary function of a router is to forward a packet toward its destination network, which is the destination IP address of the packet. To do this, a router needs to search the routing information stored in its routing table.
- A routing table is a data file in RAM that is used to **store route information about directly connected and remote networks.**

Send a Packet

PC1 Sends a Packet to PC2



Layer 2 Data Link Frame | Packet's Layer 3 data

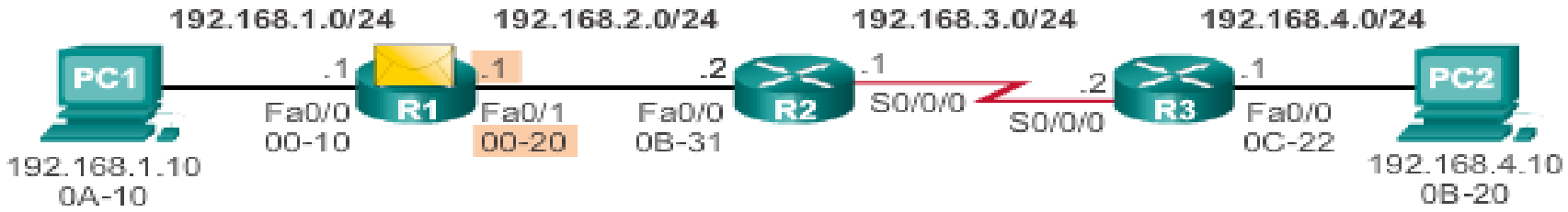
Dest. MAC 00-10	Source MAC 0A-10	Type 800	Source IP 192.168.1.10	Dest. IP 192.168.4.10	IP fields	Data	Trailer

PC1's ARP Cache for R1

IP Address	MAC Address
192.168.1.1	00-10

Forward to the Next Hop

R3 Forwards the Packet to PC2



Layer 2 Data Link Frame **Packet's Layer 3 data**

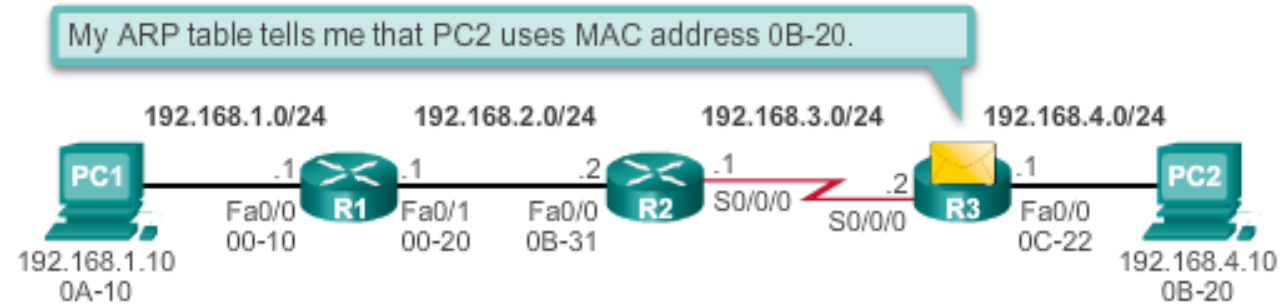
Dest. MAC 0B-31	Source MAC 00-20	Type 800	Source IP 192.168.1.10	Dest. IP 192.168.4.10	IP fields	Data	Trailer

R1's Routing Table

Network	Hops	Next-hop-IP	Exit Interface
192.168.1.0/24	0	Dir. Connect.	Fa0/0
192.168.2.0/24	0	Dir. Connect.	Fa0/1
192.168.3.0/24	1	192.168.2.2	Fa0/1
192.168.4.0/24	2	192.168.2.2	Fa0/1

Reach the Destination

R3 Forwards the Packet to PC2



Layer 2 Data Link Frame | **Packet's Layer 3 data**

Dest. MAC 0B-20	Source MAC 0C-22	Type 800	Source IP 192.168.1.10	Dest. IP 192.168.4.10	IP fields	Data	Trailer

R3's ARP Cache

IP Address	MAC Address
192.168.4.10	0B-20

R3's Routing Table

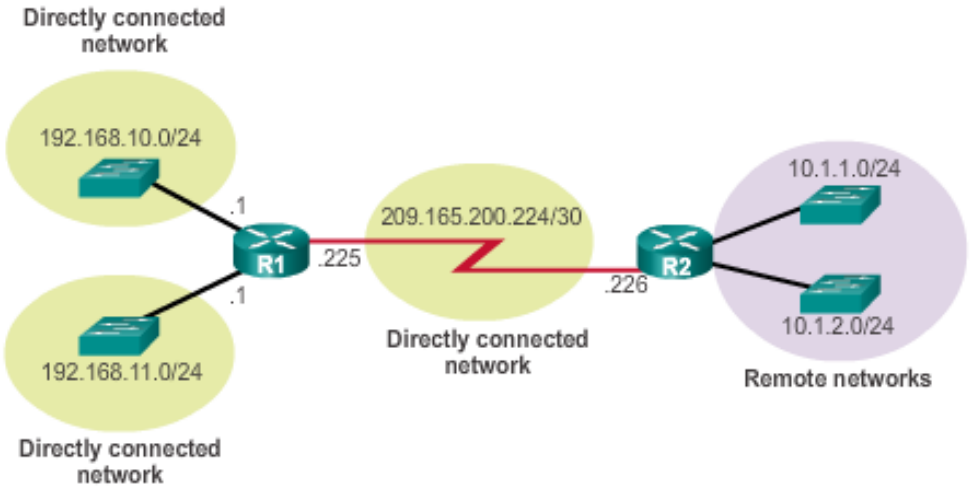
Network	Hops	Next-hop-IP	Exit Interface
192.168.1.0/24v	2	192.168.3.1	S0/0/0
192.168.2.0/24	1	192.162.3.1	S0/0/0
192.168.3.0/24	0	Dir. Connect.	S0/0/0
192.168.4.0/24	0	Dir. Connect.	Fa0/0

Best Path

- Best path is selected by a routing protocol based on the value or metric it uses to determine the distance to reach a network.
- **A metric is the value used to measure the distance to a given network.**
- Best path to a network is the path with the lowest metric.
- Dynamic routing protocols use their own rules and metrics to build and update routing tables for example:
- **Routing Information Protocol (RIP)** - Hop count.
- **Open Shortest Path First (OSPF)** - Cost based on cumulative bandwidth from source to destination.
- **Enhanced Interior Gateway Routing Protocol (EIGRP)** - Bandwidth, delay, load, reliability

The Routing Table

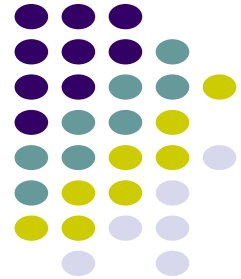
- Routing Table is a file stored in RAM that contains information about
  - Directly Connected Routes
  - Remote Routes
  - Network or Next hop Associations



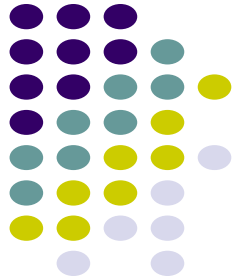
Outline

- Introduction to Static Routing
- Dynamic Routing Overview
- Routing Protocols Overview

Introduction to routing protocols



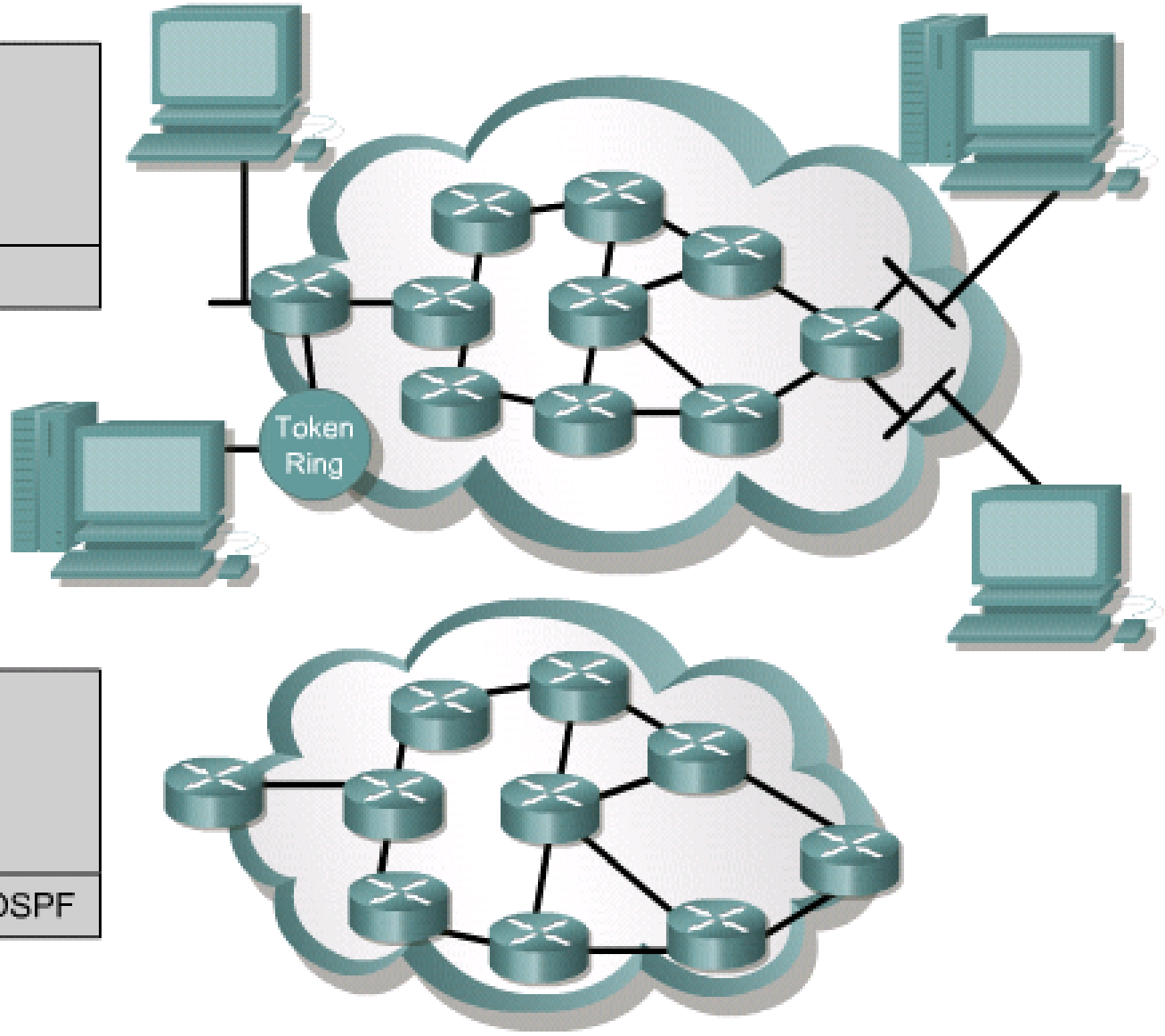
- A routing protocol is the communication used between routers.
- Examples of routing protocols are:
  - Routing Information Protocol (RIP)
  - Interior Gateway Routing Protocol (IGRP)
  - Enhanced Interior Gateway Routing Protocol (EIGRP)
  - Open Shortest Path First (OSPF)



- A routed protocol is used to direct user traffic.
- Examples of routed protocols are:
  - Internet Protocol (IP)
  - Internetwork Packet Exchange (IPX)

Routed protocol used between routers to direct user traffic

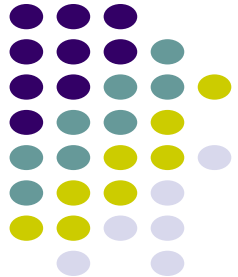
Examples: IP and IPX



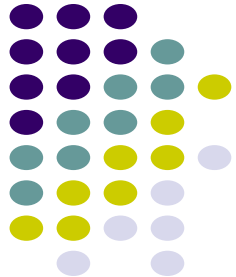
Routing protocol used between routers to maintain tables

Examples: RIP, IGRP, OSPF

Autonomous systems



- An autonomous system (AS) is a collection of networks under a common administration sharing a common routing strategy.
- To the outside world, an AS is viewed as a single entity.



- Autonomous systems (AS) provide the division of the global internetwork into smaller and more manageable networks.
- Each AS has its own set of rules and policies and an AS number that will uniquely distinguish it from other autonomous systems throughout the world.

Reach Remote Networks

A router can learn about remote networks in one of two ways:

- Manually - Remote networks are manually entered into the route table using static routes.
- Dynamically - Remote routes are automatically learned using a dynamic routing protocol.

Why Use Static Routing?

Static routing provides some advantages over dynamic routing, including:

- Static routes are not advertised over the network, resulting in better security.
- Static routes use less bandwidth than dynamic routing protocols, no CPU cycles are used to calculate and communicate routes.

Why Use Static Routing? (continued)

Static routing has the following disadvantages:

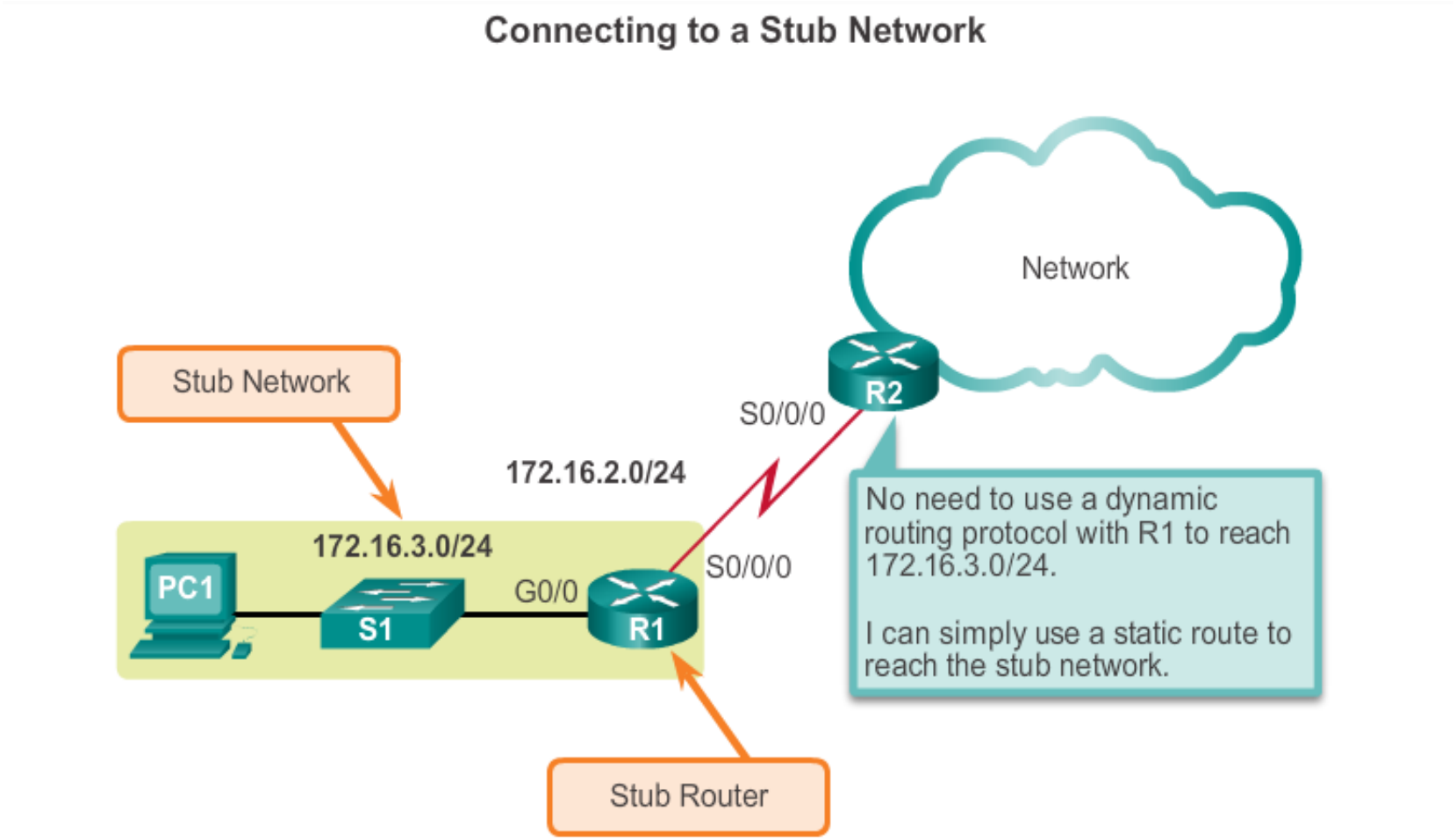
- Initial configuration and maintenance is time-consuming.
- Configuration is error-prone, especially in large networks.
- Administrator intervention is required to maintain changing route information.
- Does not scale well with growing networks; maintenance becomes cumbersome.
- Requires complete knowledge of the whole network for proper implementation.

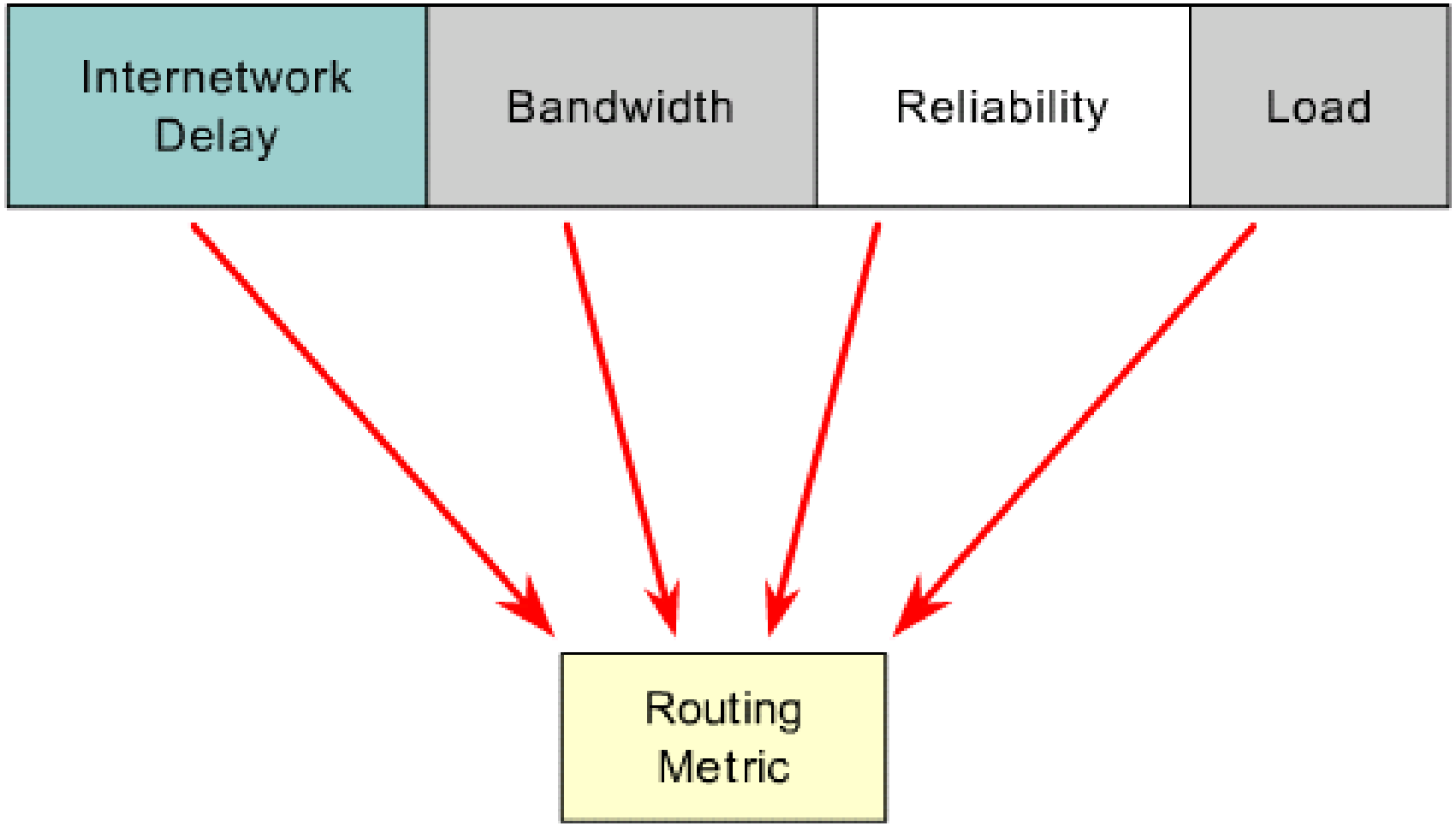
Static Route Applications

Static Routes are often used to:

- Provide ease of routing table maintenance in smaller networks that are not expected to grow significantly.
- Route to and from stub networks. A stub network is a network accessed by a single route, and the router has no other neighbors.

Standard Static Route





IPv4 Routing Protocols

- Cisco ISR routers can support a variety of dynamic IPv4 routing protocols including:
- **EIGRP –** Enhanced Interior Gateway Routing Protocol
- **OSPF –** Open Shortest Path First
- **IS-IS –** Intermediate System-to-Intermediate System
- **RIP –** Routing Information Protocol

IPv6 Routing Protocols

- Cisco ISR routers can support a variety of dynamic IPv6 routing protocols including:
- RIPng (RIP next generation)
- **OSPF v3**
- EIGRP for IPv6
- MP-BGP4 (Multicast Protocol-Border Gateway Protocol)

The Evolution of Dynamic Routing Protocols

- Dynamic routing protocols used in networks since the late 1980s
- Newer versions support the communication based on IPv6

Routing Protocols Classification

	Interior Gateway Protocols				Exterior Gateway Protocols
	Distance Vector		Link-State		Path Vector
IPv4	RIPv2	EIGRP	OSPFv2	IS-IS	BGP-4
IPv6	RIPng	EIGRP for IPv6	OSPFv3	IS-IS for IPv6	BGP-MP

Purpose of Dynamic Routing Protocols

- Routing Protocols
  - Used to facilitate the exchange of routing information between routers
- Purpose of dynamic routing protocols includes:
  - Discovery of remote networks
  - Maintaining up-to-date routing information
  - Choosing the best path to destination networks
  - Ability to find a new best path if the current path is no longer available.

Purpose of Dynamic Routing Protocols

Main components of dynamic routing protocols include:

- **Data structures -** Routing protocols typically use tables or databases for its operations. This information is kept in RAM.
- **Routing protocol messages -** Routing protocols use various types of messages to discover neighboring routers, exchange routing information, and other tasks to learn and maintain accurate information about the network.
- **Algorithm -** Routing protocols use algorithms for facilitating routing information for best path determination.

Purpose of Dynamic Routing Protocols